Unit 24 · Nuclear Physics

ANSWER KEY · FOR TEACHERS

Full marks 37

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. nucleons
2. isotopes
3. unit
4. defect
5. strong
6. fission
7. fusion
8. annihilation

Each carries 0.5 mark. **K · 4**

2 Label the diagram

1. zinc sulphide screen
2. lead block
3. source
4. gold foil

Each carries 0.5 mark. **K · 2**

3 Multiple choice

i. **b.** the atom is mostly empty space **K · 1**

Most alpha particles met nothing on their way through hundreds of layers of atoms: the atom is mostly empty.

ii. **c.** 92 protons and 146 neutrons **A · 1**

Z = 92 protons; N = A − Z = 238 − 92 = 146 neutrons.

iii. **c.** 2 times as large **U · 1**

$R = r_0 A^{(1/3)}$: $8^{(1/3)} = 2$.

iv. **c.** iron-56 and nickel-62 **U · 1**

The curve peaks at about 8.8 MeV per nucleon round iron-56 and nickel-62, the most tightly bound nuclei.

v. **b.** 0.51 MeV **A · 1**

Their total rest energy $2m_ec^2$ is shared by two equal photons: $m_ec^2 = 0.51$ MeV each.

4 Very short answers

a. **MARKING SCHEME** **K · 1**

✓ The energy needed to pull a nucleus apart into its separate nucleons.

b. **MARKING SCHEME** **U · 1**

✓ Each alpha particle meets at most one nucleus.

c. **MARKING SCHEME** **U · 1**

✓ Same Z, so the same electrons.

5 Short answers

a. **MARKING SCHEME** **U · 2**

✓ The electric repulsion between two protons is about 10^{36} times their gravitational attraction, at any distance.

✓ So another force, the strong nuclear force, must hold the nucleus together.

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b. MARKING SCHEME U · 2

- ✓ A neutron has no charge, so the nucleus doesn't repel it.
- ✓ It can drift right into the nucleus even when slow; a proton is pushed away by the nucleus's positive charge.

c. MARKING SCHEME A · 2

- ✓ k = 1: each fission leads to exactly one more; the rate stays steady (critical).
- ✓ k > 1: the fissions grow by a factor k each generation (supercritical).

6 Long answer

ANSWER U · 4

The curve starts at zero for hydrogen-1, rises steeply for small A (with peaks at helium-4, carbon-12 and oxygen-16), reaches its highest, about 8.8 MeV, round iron-56 and nickel-62, then falls gently to 7.6 MeV at uranium. When two light nuclei fuse, the product lies higher up the curve; when a heavy nucleus splits, the two middle-sized fragments also lie higher up. Either way the products are more tightly bound, with more total binding energy than what went in, and the difference is given out. Both move nuclei towards the peak.

MARKING SCHEME

- ✓ Sketch: zero at ^{1}H, steep rise, peak about 8.8 MeV near A ≈ 56–62.
- ✓ Gentle fall to about 7.6 MeV at uranium.
- ✓ Fusion and fission both give products higher up the curve (more binding energy per nucleon).
- ✓ The extra binding energy is given out: both move towards the peak.

7 Numerical problems

a. ANSWER A · 3

Separated nucleons: $8 \times 1.007\,276 + 8 \times 1.008\,665 = 16.127\,528$ u.
Mass defect: $16.127\,528 - 15.990\,523 =$ **0.137 005 u**.
Binding energy: $0.137\,005 \times 931.5 =$ **127.6 MeV**; per nucleon $127.6 \div 16 =$ **7.98 MeV**.

MARKING SCHEME

- ✓ Mass defect 0.137 005 u.
- ✓ Binding energy 127.6 MeV.
- ✓ 7.98 MeV per nucleon.

b. ANSWER A · 3

$R = r_0A\text{^}(1/3) = 1.2 \times 10^{-15} \times 56\text{^}(1/3) = 1.2 \times 10^{-15} \times 3.83 =$ **4.6×10^{-15} m**.
$V = (4/3)\pi R^3 = 4.05 \times 10^{-43}$ m^3; $m = 56 \times 1.66 \times 10^{-27} = 9.30 \times 10^{-26}$ kg.
$\rho = m/V =$ **2.3×10^{17} kg/m^3**.

MARKING SCHEME

- ✓ $R = 4.6 \times 10^{-15}$ m.
- ✓ V and m worked out.
- ✓ $\rho = 2.3 \times 10^{17}$ kg/m^3.

c. ANSWER A · 4

i. Energy per fission $= 200 \times 1.6 \times 10^{-13} = 3.2 \times 10^{-11}$ J; fissions per second $= 3.0 \times 10^{9} \div 3.2 \times 10^{-11} =$ **9.4×10^{19}**.

ii. Energy in a year $= 3.0 \times 10^{9} \times 3.15 \times 10^{7} = 9.45 \times 10^{16}$ J; $\Delta m = E/c^2 = 9.45 \times 10^{16} \div 9.0 \times 10^{16} =$ **1.05 kg**.

MARKING SCHEME

- ✓ Energy per fission 3.2×10^{-11} J.
- ✓ 9.4×10^{19} fissions a second.
- ✓ Energy in a year 9.45×10^{16} J.
- ✓ About 1 kg of mass.

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8 Think

ANSWER HA · 3

All nuclei are positive and repel each other. To fuse, two nuclei must come within about 10^{-15} m, the range of the strong force, against this repulsion. Only nuclei moving very fast can, which needs temperatures of millions of kelvin, as in the Sun's core, and the hot fuel must be held together long enough for many to fuse. Fission needs no such energy: a slow neutron, uncharged, drifts into a uranium nucleus by itself.

MARKING SCHEME

- ✓ Nuclei are positive and repel; they must get within the strong force's range (10^{-15} m).
- ✓ That needs millions of kelvin, and the hot fuel must be held together.
- ✓ Fission is set off by an uncharged slow neutron, with no repulsion to overcome.

9 Activity: Reading the binding energy curve

(not marked)

WHAT STUDENTS SHOULD FIND

About 1.1, 7.1, 8.8 and 7.6 MeV per nucleon; totals about 2.2, 28, 490 and 1,780 MeV. Iron-56 is the most tightly bound per nucleon; uranium-235 has the largest total, simply because it has the most nucleons. Tightness is measured per nucleon, not in total.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	8	12	14	3	**37**

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